ACOUSTIC INTERACTION OF HUMPBACK WHALES AND RECREATIONAL FISHING VESSELS IN A TEMPERATE FJORD: MEASUREMENTS IN RIVERS' INLET, BRITISH COLUMBIA

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Abstract: *Underwater environments are acoustically complex and highly variable. Natural processes, biological organisms and human activities all emit sound, at various levels and over broad frequency ranges. To facilitate ocean resources management and mitigate impacts of anthropogenic noise, areas where these sources interact in the space, time and frequency domains need to be identified. This paper presents analyses of field measurements taken on the west coast of Canada in August/September 2008, along the temperate fjord of Rivers' Inlet (British Columbia). Humpback whales* (Meganoptera novaeangliae) *use this fjord as a feeding ground, sharing it with recreational fishing craft mostly consisting of small boats (20 m or less). Measurements were taken over several days at regularly-spaced locations in deep water from the mouth of the fjord inward, using a broadband (0.1 – 30 kHz effective bandwidth) hydrophone deployed 10 m deep. Analysis focused on the joint use of acoustic bandwidths by humpback whales and recreational fishing vessels. Recorded spectra of humpback whale vocalizations and vessel noise overlapped considerably in the range 0.1 – 1 kHz. At the distances recorded (> 1 km) vessel noise produced a mean increase of 4 dB above background levels in this range. Ambient noise levels are also discussed briefly with reference to previous studies.*

Keywords: *anthropogenic noise, humpback whales, fjord, ship noise*

1. INTRODUCTION

There is concern that anthropogenic noise, from shipping and other activities, may have a detrimental impact on marine life [1]. Ongoing research efforts are seeking to more fully understand the extent of acoustic interaction between man-made sources and species that rely on sound to navigate and communicate, especially cetaceans. Particular attention has been paid to the potential for acoustic masking of biologically-important sounds [2]. To date, impact studies of vessel noise and cetaceans have concentrated on the effects of commercial shipping and whale-watching activities. In the present study, we examine the potential for acoustic disruption to foraging humpback whales by recreational fishing vessels in the semi-enclosed environment of a temperate fjord, focusing on the frequency characteristics of the respective sources.

Humpback whales migrate from winter mating grounds in tropical waters to summer feeding areas in temperate and polar waters. The North Pacific population is known to feed in coastal regions stretching from Southern California to Alaska, including British Columbia [3]. Unlike smaller cetaceans such as the bottlenose dolphin, the aural sensitivity of the humpback whale has not been examined using audiometric methods both for practical and legal reasons [4]. However, frequency ranges significant for intraspecific communication may be inferred from the acoustic bandwidths of social sounds.

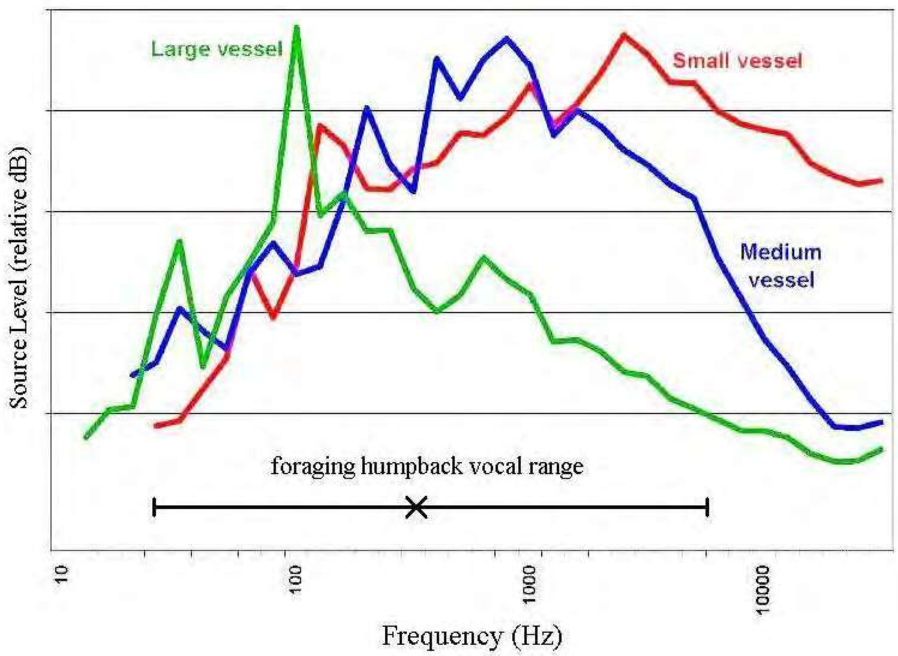

Fig.1: Representative relative source levels of vessels according to size with range of foraging humpback vocalizations recorded to date (cross denotes mean spectral peak recorded by Stimpert et al. [7]; ship spectra adapted from Kipple [12])

Different sonic behaviour has been reported during feeding, migration and breeding. Relatively few acoustic observations of foraging humpbacks have been made, as most work has focused on the study of songs (associated with, but not limited to, the breeding season [5]). Vocalizations recorded during foraging activity have been reported in the northeast Pacific and northwest Atlantic, with peak frequencies ranging from around 25 Hz [6] to as high as 6 kHz in the most recent study [7], where a mean peak frequency of 329 Hz was observed. Humpback whales also communicate using non-vocal surface-generated sounds such as breaches and slaps, especially in the presence of increased ambient noise [8].

Little published data exists for the noise radiated by small- to medium-sized vessels. It is currently limited to spectra of two rigid-hulled inflatable boats with outboard motors [9] and studies of recreational vessels in Glacier Bay, Alaska [10, 11]. For small recreational vessels of the type observed in Rivers' Inlet (length < 20 m), reported spectra [10] peaked at between 0.4 and 5 kHz at levels of 150-181 dB re 1 μPa at 1 yard (0.9 m).

Collated data presented by Kipple [12] (Fig. 1) show how the frequencies of spectral peaks vary inversely with ship size, ranging from tens of hertz for large vessels (> 190 m) to a few thousand hertz for small vessels (< 9 m). Given that most humpback whale social sounds have peak frequencies in the range 0.1-1.0 kHz, small- and medium-sized boats may cause greater acoustic disruption at short range than larger commercial ships.

2. DATA COLLECTION AND ANALYSIS

2.1. Field Measurements

Measurements of ambient noise underwater were acquired as part of a larger research programme, funded by the Earthwatch Institute and looking at grey and humpback whales summering along the British Columbia coast north of Vancouver Island. These studies focused on the abundance, distribution and movements of grey and humpback whales, and the acoustic measurements were an add-on to the main whale-watching activities. Rivers' Inlet is located in the central coast area of British Columbia, approximately 500 km northwest of Vancouver. It is 46.3 km long, has a mean width of 3.0 km, a mean depth of 295 m and a maximum depth of 365 m [13]. Although morphologically similar to fjords, the sills at the mouth of inlets are usually not shallow. This is the case here, with recorded depths of 110 m or more. Rivers' Inlet is an important ground for recreational fishing (primarily of salmon) and hosts a relatively large number of small fishing vessels in season. It also hosts a sizeable population of humpback whales (but no other type of whales in summer, as could be attested during the field observations). A small boat was deployed far from the main research vessel (F/V *Stardust*, whose engine was switched off) and drifted freely during measurements taken at regular waypoints throughout Rivers' Inlet (Fig. 2). Most waypoints were surveyed several times (see Table 1) to assess the variability of environmental conditions. Ambient noise was measured over several minutes with a single hydrophone SQ26-07 (manufactured by Cetacean Research Technology, Seattle, USA). This hydrophone is omnidirectional at all frequencies considered, as confirmed by earlier tank tests. Its operational frequency band ranges from 100 Hz to 30 kHz, and its sensitivity is nearly constant in the measurement range. The preamplifier gain was fixed to enable subsequent calibration. The 10-m shielded cable allowed for deployment to nearly 9.5 m below the water line over the low gunwale of the supporting vessel. The data from the hydrophone was input to a Zoom H2 digital recorder (sample rate 96 kHz, 24-bit WAV format). Measurements covered an effective broadband range of 100 Hz to 30 kHz. They were acquired in water always deeper than 110 m (300 m on average) and in several distinct environments (from the mouth of the inlet to well inside its main portion) (Fig. 2). The sea state and prevalent weather were recorded each time, along with the presence of humpback whales in the visual range (several km).

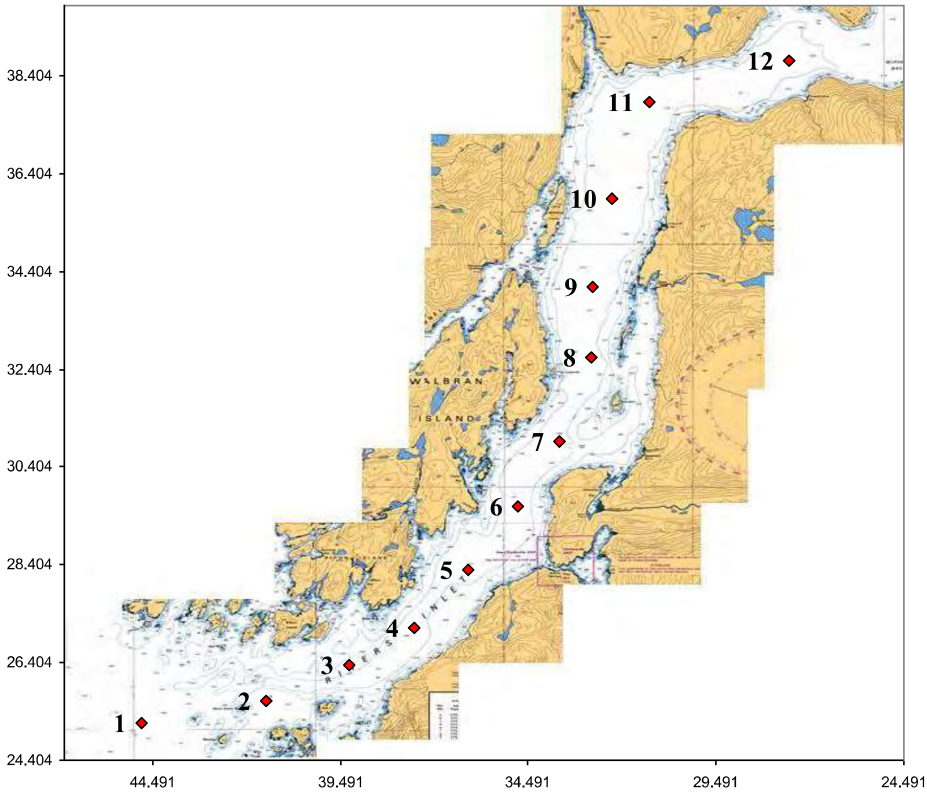

Fig.2: Locations of field measurements in Rivers' Inlet, British Columbia

Date	01/08/2008	02/08/2008	08/08/2008	09/08/2008
Waypoints measured	1-9	1-12	1, 5, 9	1, 5, 8-12

Table 1: Field log of waypoints measured (locations shown in Fig. 2)

2.2. Data Analysis

Data was initially reviewed aurally using full-bandwidth sound reproduction, and an event matrix was created documenting the audible presence of ship noise, humpback whale vocalizations, and platform noise in each 10 s section of the dataset. This enabled a more focused spectral analysis of specific features in the data.

The recordings were analysed using custom-designed MATLAB algorithms. These allowed for several windowing options (Hanning, Hamming, Blackman and Dirichlet) with adjustable length and overlap, accessible via a graphical user interface. Humpback whale vocalizations were catalogued according to peak frequency, duration, and the presence of vessel noise. For the analysis of ambient noise and ship noise, representative 10-second segments were selected in periods when platform noise was minimal. These were analysed in 1/12 octave bands (referenced to 1 kHz). The field recordings were converted from normalised WAV levels to pressures using the gain of the field recorder - measured using a signal generator at a range of frequencies and input voltages - and the hydrophone sensitivity specifications (-168 dB re 1 V μPa^{-1} at 0.1-30 kHz).

3. RESULTS

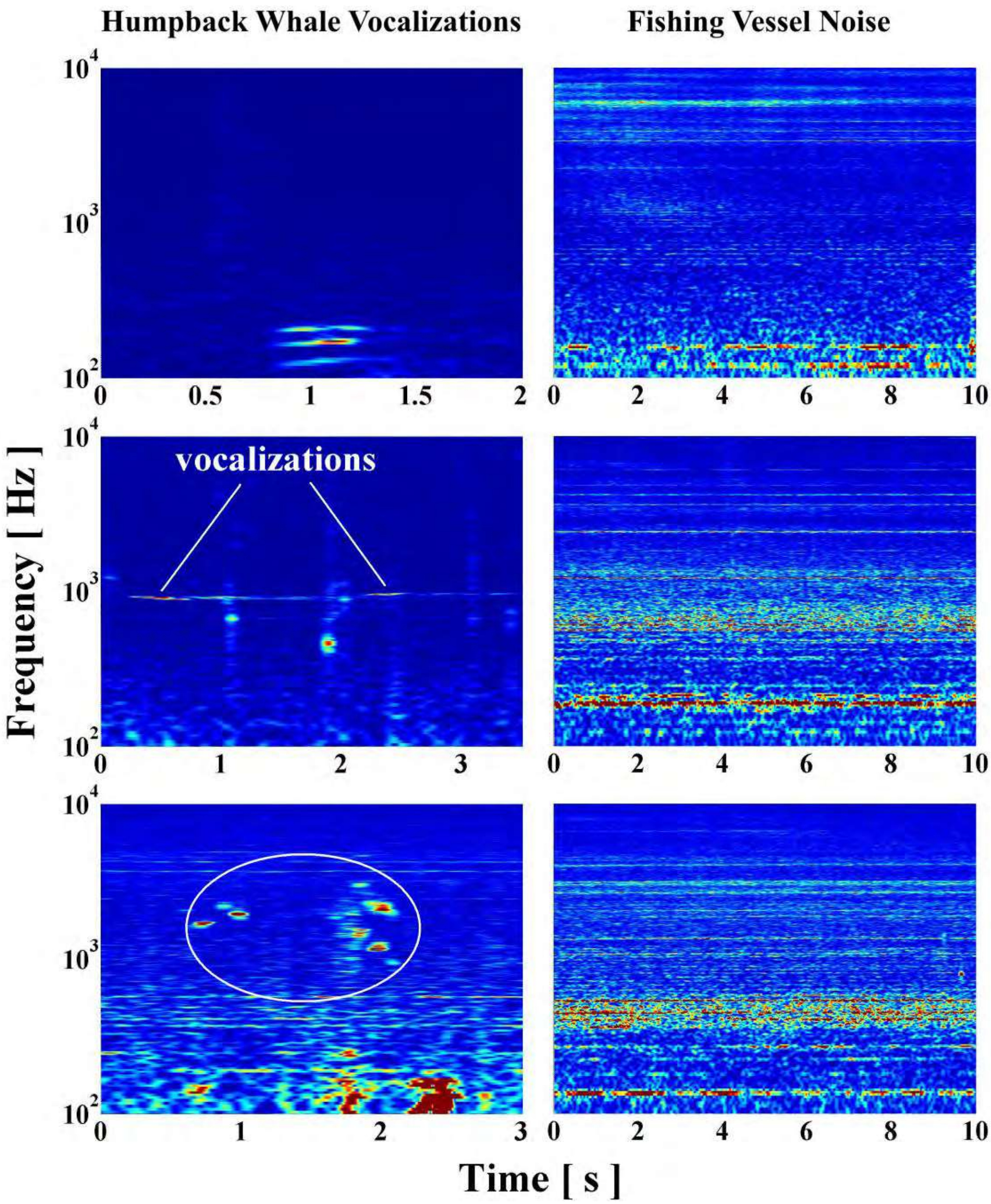

Fig.3: Left column: example humpback whale vocalizations. Note platform noise in middle and bottom plots and ship noise in bottom plot. Right column: typical ship spectra (across the same frequency range). Processing: 0.2-s (19,200-point) Hanning window, 99% overlap. Colour scale differs among plots.

3.1. Humpback Whale Vocalizations

Vocalizations were recorded at four locations in measurements from 8 and 9 August, with and without audible vessel noise. These corresponded to sightings of humpbacks around the time of measurement. No humpback vocalizations were audible in the measurements from 1 and 2 August, nor were any whales sighted. 24 events were detected in total, where sounds separated by less than one second were counted as one event.

Harmonic and non-harmonic sounds were observed, with spectral peaks ranging from 74 to 2,109 Hz (two peaks were below the flat frequency response of the hydrophone, at 74 and 79 Hz), with a mean of 891 Hz. Three characteristic examples are presented in Fig. 3. Durations of individual sounds were between 0.02 and 0.9 s, with a broad trend of shorter duration at higher frequency. No apparent variation was observed with the presence of audible ship noise, though a larger dataset might reveal more nuanced effects.

This anecdotal sample of foraging humpback whale vocalizations indicates that the humpback whales observed communicate in the fjord using frequency bandwidths consistent with the ranges reported in the literature.

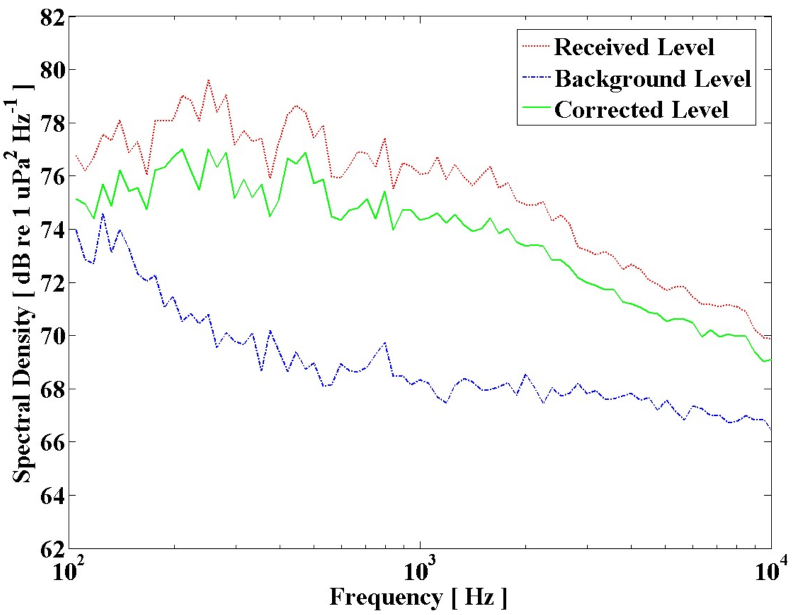

Fig.4: Example of 1/12 octave band spectrum of received ship noise with background correction. Sea state 0-1, waypoint 4 (see Fig. 2 for location).

3.2. Ship Noise

Ship noise was observed at all locations except waypoints 6 and 7 (see Fig. 2), in 16 of the 31 measurements taken. Spectral peaks of the 10 s samples analysed were between the lower bandwidth limit of 100 Hz and 281 Hz, with received levels of 74-84 dB re 1 µPa Hz^{-1} (not background corrected). It is possible that overall spectral peaks were below the hydrophone bandwidth limit of 100 Hz. In general, secondary spectral peaks were widely distributed between 0.1 and 1 kHz (see Fig. 3). For 7 of the 16 samples, an ambient noise measurement with equivalent waypoint and sea state was available. In the range 0.1-1 kHz, received sound levels for these samples were raised by an average of 4 dB by the presence of ships. An example spectrum illustrating the sound level increase due to vessel noise and the background-corrected received ship noise level is presented in Fig. 4.

Distances to observed vessels were estimated to be ~ 1 km. As these were not recorded accurately, no attempt was made to calculate source levels. A simple propagation loss model [1] gives an order of magnitude estimate of 60 dB km^{-1} at 0.1 kHz, indicating the levels recorded are broadly consistent with those reported by Kipple for similar craft [10]. Peak frequencies for the received ship spectra were lower than those reported by Kipple. This could be an effect of propagation loss, which is proportional to frequency.

3.3. Ambient Noise

Periods of ambient noise free from audible vessel noise and excessive platform noise were identified in 10 of the measurements, at waypoints 4-10 (see Fig. 2). Mean 1/12 octave spectra are presented in Fig. 5 according to sea state (there was no rainfall during these measurements). These spectra are considerably higher than the Wenz curves, especially at low wind speeds and higher frequencies, suggesting an increased noise floor in the fjord environment. The ambient noise levels above 1 kHz are lower than measurements of a 400 m deep Alaskan fjord reported by Schilt [14] for wind speeds of 3 and 5 m s^{-1}, with a similar negative gradient observed. The spectral shapes differ in that the sound level does not decrease below 1 kHz. This variation could be due to several factors, including platform noise, undetected vessel noise, and noise from freshwater tributaries that was identified in some recordings.

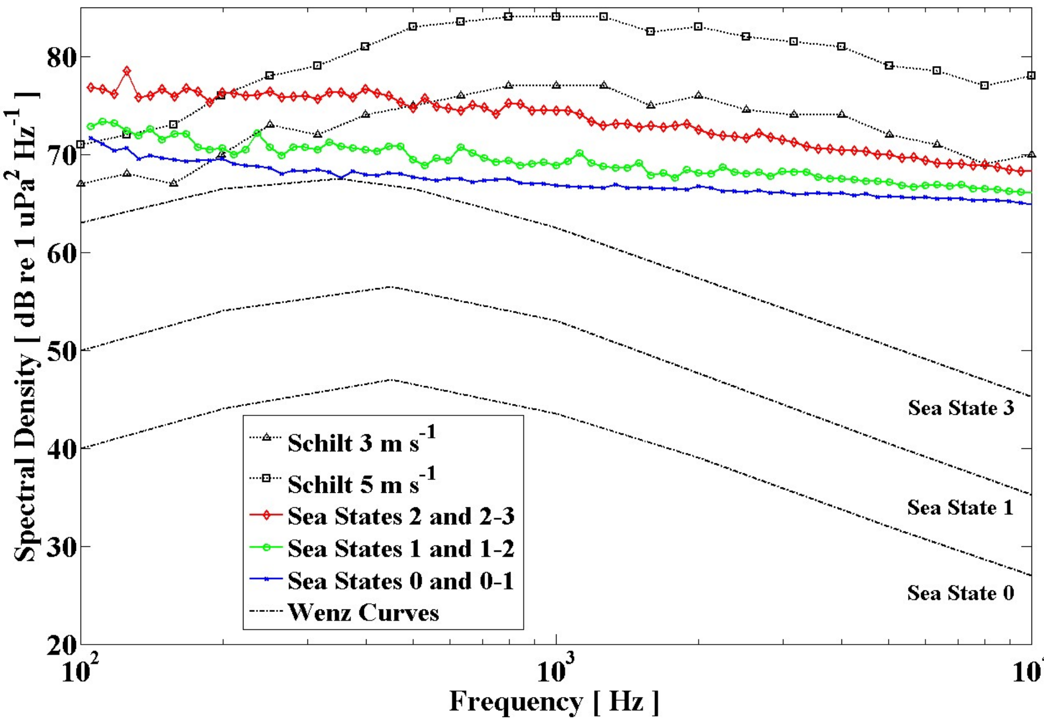

Fig.5: 1/12 octave band ambient noise according to sea state compared to previous studies. Wind speeds for sea states 0-3: 0-1.5, 1.6-3.3, 3.4-5.4 and 5.5–7.9 m s^{-1}.

4. DISCUSSION

The concentration of spectral energy in observed ship noise below 1 kHz coincides with the majority of spectral peaks in humpback whale vocalizations recorded (see Fig. 3), which were toward the upper end of the 0.1-1 kHz range with a mean of 891 Hz. This mean is based on a small, anecdotal sample of vocalizations, and a recent study [7] conducted in the Northwest Atlantic indicates a more representative figure of 329 Hz for foraging humpback whales. This is closer to the peak frequencies of received vessel noise observed in the fjord (100-281 Hz), which may be higher at close range due to propagation loss. In the subset of data where background levels were available, received vessel noise raised the ambient level by 4 dB on average in the range 0.1-1 kHz. It was also noted that ambient noise levels in the fjord were higher than the canonical Wenz curves, though this may be due to contamination from other sources, especially at low frequencies.

We conclude that fishing vessels in the fjord contribute to increased noise levels in the frequency bandwidths used by foraging humpback whales. Further work is needed to establish whether levels of anthropogenic noise in the inlet are potentially harmful to the whales that forage there in the summer feeding season. This could lead to recommendations for the regulation of recreational fishing activities during this period, both in the study area and elsewhere.

5. ACKNOWLEDGEMENTS

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